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Lifting an unexpectedly heavy object: the effects on low-back loading and balance loss

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Abstract

Objective. This study evaluates the effects of lifting an unexpectedly heavy object on low-back loading and loss of balance.

Background. It is often suggested that lifting an unexpectedly heavy object may be a major risk factor for low-back pain. This may lead to an increase in muscle activation, stretch of ligaments and posterior disc, and loss of balance.

Methods. Nine healthy male subjects were asked to pick up and lift a box as quickly as possible. The weight of the box was unexpectedly increased by 5 or 10 kg. Kinematics and force data were recorded throughout the experiment.

Results. Lifting of an unexpectedly heavy box led to a decrease in maximum torque of the low back compared to lifting the same box mass with correct expectation. The maximum lumbar angle did not increase compared to the light box condition. Only the threat to balance appeared to be somewhat increased.

Conclusions. The lifting of an unexpectedly heavier box appeared not to lead to an increased balance loss or a clearly increased stress of the structures of the low back, although a burst of abdominal muscle activity was found in one condition. These results do not fully clarify the assumed relation between lifting unexpectedly heavy objects and low-back injury.

Relevance

A commonly cited cause of low-back pain is the lifting of an unexpectedly heavy object. A study of the responses to such perturbation is important to an understanding of spine mechanics and the etiology of low-back injury.

Keywords: Lifting; Muscle activation; Spinal load; Movement control; Unexpectedly heavy mass

1. Introduction

From epidemiological research it can be concluded that sudden, unexpected load on the back is related to a high incidence of low-back pain [1,2]. In addition, the development of low-back pain is believed to be related to the act of lifting [3]. From these statements it is often concluded that the lifting of an object with incorrect mass knowledge may lead to low-back pain. Lifting an unexpectedly lighter object leads to an increased mechanical loading on the lumbar spine and to an increased risk of losing balance [4]. The effect of lifting an unexpectedly heavy object on low-back loading or losing balance, however, has not been studied so far.

With the lifting of an unexpectedly heavy object, several factors can be expected to cause a high low-back load and therefore an increased risk of injury. The first factor is the low muscle activity in relation to the mass of the object that the subjects are lifting. Lifting an unexpectedly heavy object entails an underestimation of the load mass, because the information about the actual mass of the object can only be obtained after the subjects have exerted a force on the object [5]. Due to the underestimation of the load mass, the subjects will apply a muscle moment smaller than required to actually lift the object. Insufficient activation of the trunk extensor muscle fibers can lead to an increased trunk flexion under the influence of gravity acting on the load and upper body. This increased trunk flexion may coincide with eccentric muscle actions (lengthening of active muscles), which are more likely to cause disruption or injury to muscle tissue than concentric actions [6]. Moreover, due

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to the increased trunk flexion passive tissues such as ligaments and the posterior disc may be unduly strained, which in extreme cases can cause ruptures [7].

A second factor is the reaction of the subject after the perturbation. In experiments in which subjects had to withstand an unexpectedly applied flexion moment during stance, an increased activity of the trunk muscles was found [8–10]. An increased activity of the trunk muscles increases the mechanical load on the back by increasing the compression force on the spine.

The final factor that may increase the risk of injury to the spine when lifting an unexpectedly heavy object is loss of balance. Falls that occur while lifting an object are associated with low-back injuries [11]. It had been shown that subjects tend to lose balance, that is, they had to make serious efforts to prevent falling, in 92% of all lifting trials in which the mass of a box was overestimated [4]. An underestimation of the object mass may also cause a threat to balance, since the addition of the extra mass will shift the center of mass (CoM) forwards. This may increase the horizontal velocity of the CoM, which may cause the CoM to cross the stability boundary with respect to the base of support [12].

The magnitude of the injury risk may be related to the size of the perturbation. In an experiment in which subjects had to withstand a forward flexion moment, it was observed that with increasing perturbations the trunk muscle co-activation correspondingly increased [9]. In addition, the injury risk may be related to the expected object mass to be lifted. In the same experiment as described above, it was found that pre-activation of trunk muscles can serve to reduce the flexion displacements caused by rapid loading [9]. The pre-activation of trunk muscles will be less when the subjects expected to lift a light object instead of a heavier object [13].

This study was designed to investigate the lifting of an unexpectedly heavy object in a whole body, bimanual lifting task. The following questions will be answered:

- What is the effect of the lifting of an unexpectedly heavy object on low-back loading?
- How is this effect mediated by the expected load mass and the size of the perturbation?

Low-back load was studied by analyzing the torque at the L5-S1 joint, co-activation of trunk muscles and maximum lumbar angle. The same questions were answered with respect to balance loss, which was evaluated by determining whether subjects were forced to make a step. In addition, the horizontal and angular momentum were analyzed to quantify the magnitude of the balance threat imposed by the lifting task [14,15]. In this study, conditions were compared where subjects either had mass knowledge or did not have the correct mass knowledge prior to lifting a box. The subjects were instructed to lift the box as fast as possible to prevent adaptations in muscle force in the time period between the grasp of the box and the lift off.

2. Methods

2.1. Subjects

Nine healthy male subjects (age 22.4 yr (SD 1.5 yr), height 1.80 m (SD 0.07), body mass 72.7 kg (SD 7.9)), none of whom had a history of back pain, participated in the experiment. All subjects were informed that they were to perform a series of lifting tasks, in which a box had to be lifted. The true purpose of the experiment was not revealed to the subjects. The subjects all provided written consent prior to the experiment. All the experimental procedures were undertaken with the approval of the institute's ethical committee.

2.2. Experimental procedure

The subjects were asked to bend over from standing and to pick up and lift a PVC box (0.24 m $\times$ 0.34 m $\times$ 0.42 m) that stood 0.25 m in front of their toes and 0.10 m above floor-level. No instructions were given about the starting posture or lifting technique. However, the subjects were instructed to lift the box as quickly as possible, to prevent them from perceiving the actual load mass in the initial part of the lift. Loads were placed inside the box, which was covered with a lid to prevent visual identification of the content. The mass of the box was 1.6, 6.6, 11.6 or 16.6 kg. The subjects were instructed to keep their heels on the ground and to restrict their movement to the sagittal plane. The subjects performed practice trials using the 16.6 kg box to familiarize themselves with the experimental task.

The experiment consisted of five bouts of lifting movements, of which the sequence was varied between the subjects. Two blocks consisted of eight lifting movements of a constant load (11.6 or 16.6 kg). In three blocks, the load of the box was unexpectedly increased by 5 or 10 kg after the subject had performed at least five lifting movements (see Table 1). Within a block, the subjects were asked to stand on one leg. During the standing on one leg, the subjects were secluded from the environment by headphones with loud music and by non-transparent glasses, so that it was possible to change the loads in the box without the subject's knowing. The subjects were asked to stand on one leg in a different order between the blocks (see Table 1), to make sure that the subjects did not expect the increase in box mass.

2.3. Kinematic data collection and biomechanical model

A dynamic two-dimensional linked segment model [16] was used to describe the lifting movement and to calculate the torque at the lumbo-sacral (L5-S1) joint. This model requires kinematic data, segment anthropometry and ground reaction forces. During the lifting

Table 1
The experimental procedure (the number between brackets is the expected load mass)[a]

Condition (kg)	Number of lifting movements before the load change occurred	Lifting movements after which the subjects were asked to stand on one leg
11.6	–	Second and sixth
16.6	–	Seventh
11.6 (1.6)	6	Second, fourth and sixth
16.6 (6.6)	7	Second and seventh
11.6 (6.6)	5	First, second, third, fourth and fifth

[a] 11.6 kg: 11.6 kg box expected; 16.6 kg: 16.6 kg box expected; 11.6 (1.6) kg: the condition in which the subjects expected to lift a 10 kg lighter box of 1.6 kg; 16.6 (6.6) kg: the condition in which the subjects expected to lift a 10 kg lighter box of 6.6 kg; 11.6 (6.6) kg: the condition in which the subjects expected to lift a 5 kg lighter box of 6.6 kg.

movement, the positions of 17 LEDs were recorded at 100 Hz using an Optotrak recording system. Ten LEDs were placed on the skin on the right side of the body to indicate the location of the following joints: the fifth metatarsophalangeal joint, the ankle joint (the distal part of the lateral malleolus), the knee joint (epicondylus lateralis), the hip joint, the lumbo-sacral joint (as in [16]), the spinous processes of the first thoracic vertebra, the caput mandibula (the head), the lateral border of the acromion, the elbow joint (epicondylus lateralis) and the wrist joint (ulnar styloid). Two LEDs were placed on the left side of the body at the position of the greater throchanter and the L5-S1 joint. This was done to improve the estimation of the position of both these joints, which was calculated by taking the mean of the left and right value. The coordinates of the acromion marker were used to determine the position of the shoulder joint. The coordinates of the joint position defined eight body segments: the foot, lower leg, upper leg, pelvis, upper trunk plus head, upper arm, fore arm and hands. Five markers were attached to the box to be able to infer the saggital plane location of the box center of mass. Anthropometric data (body mass, length of segments, standing height) were measured.

Simultaneously with the movement registration, the ground reaction forces (Fg) were recorded by means of a strain gauge force platform (1.0 m $\times$ 1.0 m). The analog force signals were amplified, filtered (10 Hz, fourth order Butterworth filter), sampled (100 Hz) and stored. From the distribution of the force components, the point of application of the force vector was calculated in the anterior–posterior position.

2.4. Electromyography

The electromyography of the prime back and abdominal muscles was measured to obtain an indication of the contribution of the muscle co-contractions to the back load. Prior to the experiment surface EMG-electrodes (Ag/AgCl) were attached after cleaning and gentle abrasion of the skin. The center-to-center electrode distance was 2.5 cm. The EMG-signals were recorded from parts of the left medial and lateral lumbar erector spinae muscles, part of the thoracic erector spinae muscles and the mm.obliques externus and internus. The electrodes were positioned 3 cm lateral to the midspine at the level of T9 and L2 and 6 cm lateral to the midspine at the level of L1. The oblique muscles were subdivided into two functional sections, a lateral and an anterior part [17], which were monitored at locations described by Dieën and Kingma [18]. The EMG signals were amplified, band-pass filtered (10–200 Hz) and stored on a disk at a sample frequency of 800 Hz. The EMG signals were high-pass filtered (digital finite impulse response filter, 30 Hz) to reduce the influence of possible movement artefacts and ECG [19], rectified and low-pass filtered (second order Butterworth filter, 2.5 Hz [20]). All digital filtering was bi-directional to avoid phase shifts of the signals.

2.5. Data analysis

The lumbar angle was defined as the angle between the line through the hip joint and L5-S1 and the line through L5-S1 and T1. During stance the lumbar angle was zero, with flexion the lumbar angle increases. The mass of each segment, as well as the position of the segmental center of mass (except for the trunk) and the segmental moment of inertia were calculated according to Looze et al. [16] and Plagenhoef et al. [21]. The position of the trunk center of mass was calculated according to an optimization procedure, which improved the estimation of the trajectory of the body center of mass [22]. The body center of mass was calculated from the segments' masses and center of mass locations. To study the disturbance of balance, the instantaneous horizontal and angular momentum of the CoM of the whole body [14], including the mass of the box after pick-up, was calculated according to Toussaint et al. [15].

The lifting movement in which the mass of the box was unexpectedly changed, as well as the last three and lifting movements before the mass was unexpectedly changed, were recorded. In the blocks with constant box mass the last three lifting movements were recorded. To permit averaging of trials, each trial was synchronized in time to the moment the subjects started to lift the box. During the start of the box grasp, most subjects exerted a downward force on the box moving the markers on the box downwards. When the subjects actually started to lift the box, the height of the markers increased. Therefore the start of the box grasp was determined from the lowest position of the box markers. When the subject did not exert a downward force on the box, the last sample in which the box markers did not move determined the start of the lifting phase. A total of 1.00 s (400 ms before and 600 ms after $t = 0$) was analyzed, according to the lifting movement that was performed most quickly. Next, the three recorded movements of the same mass, and the simultaneously recorded EMG, were averaged and taken as the mean of that mass condition.

2.6. Statistical analysis

An analysis of variance with repeated measures (ANOVA) was used to test the effects of condition and time on the instantaneous values of lumbar angle, torque at the L5-S1 joint, angular momentum and the linear momentum. The maximum values of the lumbar angle and the torque at the L5-S1 joint were separately tested. The degrees of freedom were adjusted to the number of valid observations. Significant interaction effects were examined with paired t-tests (two-sided) to test which conditions significantly differed from each other. In view of the intra-individual variance this was not done for the muscle activity data. Effects were considered to be significant at $P < 0.05$.

3. Results

The data of seven subjects were used for the analysis. Data sets of two subjects were incomplete, and were hence discarded. The muscle activity of the erector spinae muscles at the level of L1 resembled the activity of the erector spinae muscles at the level of L2 in all mass conditions. Therefore, these muscles are described together as lumbar muscles. Not all graphs of muscle activity against time will be shown, only the most representative graphs are selected. Prior to the box grasp no significant differences between the expected (light) mass condition and the mass change condition were found in any parameter. Therefore, only the period after the subject started to lift the box is described here.

3.1. Unexpectedly heavy object

Lifting an unexpectedly 10 kg heavier box (11.6 kg) did not appear to cause an increase in low-back load, as was evidenced by the maximum torque at the L5-S1 joint and the maximum lumbar angle. In contrast, the maximum torque in the mass change condition was significantly smaller than in the condition in which the subjects were lifting the 11.6 kg box with correct mass knowledge (Tables 2 and 3). Only after 300 ms the torque at the L5-S1 joint in the unexpectedly heavy box condition was higher than in the 1.6 kg box condition (Fig. 1). However, the torque did not increase to the same level as in the first peak. The maximum lumbar angle in the unexpectedly heavy box condition was the same as in the 1.6 kg box condition (Tables 2 and 3), only the extension velocity was decreased compared to the conditions in which the subjects had correct mass knowledge (Fig. 2). When the box was heavier than the subjects expected, one subject dropped the box just after he had lifted it.

Approximately 100 ms after the subjects grasped the unexpectedly heavy 11.6 kg box a burst of muscle ac-

Table 2
The averaged maximum values of the torque at the L5-S1 joint and the averaged maximum lumbar angle of all subjects for the different mass conditions (standard error of mean)[a]

	1.6 kg	6.6 kg	11.6 kg	16.6 kg	11.6 (1.6) kg	11.6 (6.6) kg	16.6 (6.6) kg
Torque at L5-S1-joint (in Nm)	294.08 (16.5)	287.46 (17.2)	316.31 (20.7)	323.74 (13.6)	302.09 (11.5)	294.55 (15.8)	300.47 (18.4)
Lumbar angle (in deg.)	72.2 (6.3)	73.9 (6.3)	76.2 (6.3)	77.9 (6.9)	73.9 (5.7)	72.8 (5.2)	73.3 (6.9)

[a] 1.6 kg: 1.6 kg box expected; 6.6 kg: 6.6 kg box expected; 11.6: 11.6 kg box expected; 16.6: 16.6 kg box expected; 11.6 (1.6) kg: the condition in which the subjects expected to lift a 10 kg lighter box of 1.6 kg; 16.6 (6.6) kg: the condition in which the subjects expected to lift a 10 kg lighter box of 6.6 kg; 11.6 (6.6) kg: the condition in which the subjects expected to lift a 5 kg lighter box of 6.6 kg.

Table 3
The results of the paired t-test, which was used to test if the maximum values of the conditions were significantly different from each other[a]

	6.6–1.6 (6.6) kg	1.6–11.6 (1.6) kg	6.6–16.6 (6.6) kg	11.6 (6.6)– 11.6 kg	11.6 (1.6)– 11.6 kg	16.6 (6.6)– 16.6 kg	11.6 (1.6)– 11.6 (6.6) kg	11.6 (1.6)– 16.6 (6.6) kg
Torque at L5-S1 joint	n.s.	n.s.	n.s.	$P < 0.05$	$P < 0.05$	n.s.	n.s.	n.s.
Lumbar angle	n.s.	n.s.	n.s.	n.s.	$P < 0.01$	n.s.	n.s.	n.s.

[a] 1.6 kg: 1.6 kg box expected; 6.6 kg: 6.6 kg box expected; 11.6: 11.6 kg box expected; 16.6: 16.6 kg box expected; 11.6 (1.6) kg: the condition in which the subjects expected to lift a 10 kg lighter box of 1.6 kg; 11.6 (6.6) kg: the condition in which the subjects expected to lift a 5 kg lighter box of 6.6 kg; 16.6 (6.6) kg: the condition in which the subjects expected to lift a 10 kg lighter box of 6.6 kg.

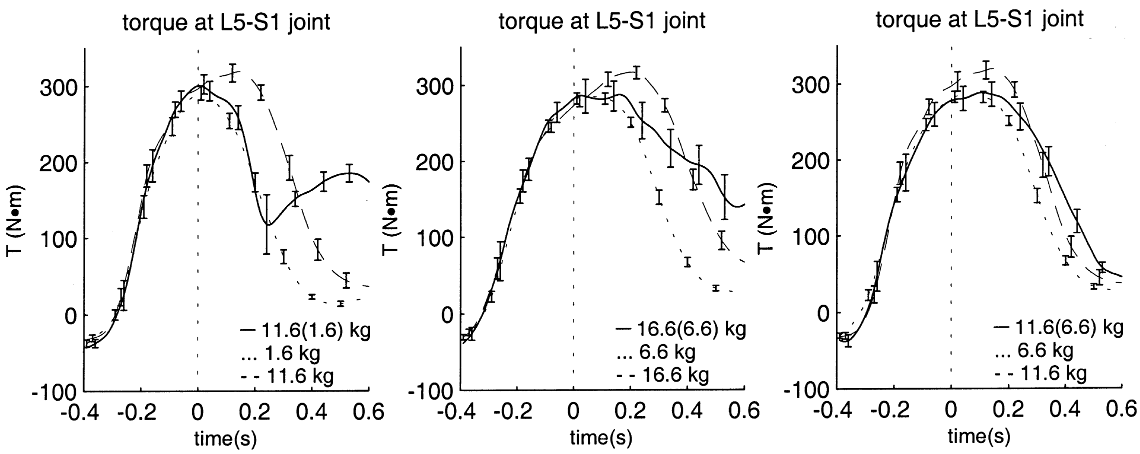

Fig. 1. Time series of the torque at the L5-S1 joint for the three mass change conditions. The solid line represents the unexpected mass change condition. The dotted line represents the heavy mass condition and the dashed–dotted line the light mass condition. The bars indicate one standard error of the mean. At time zero the box is grasped.

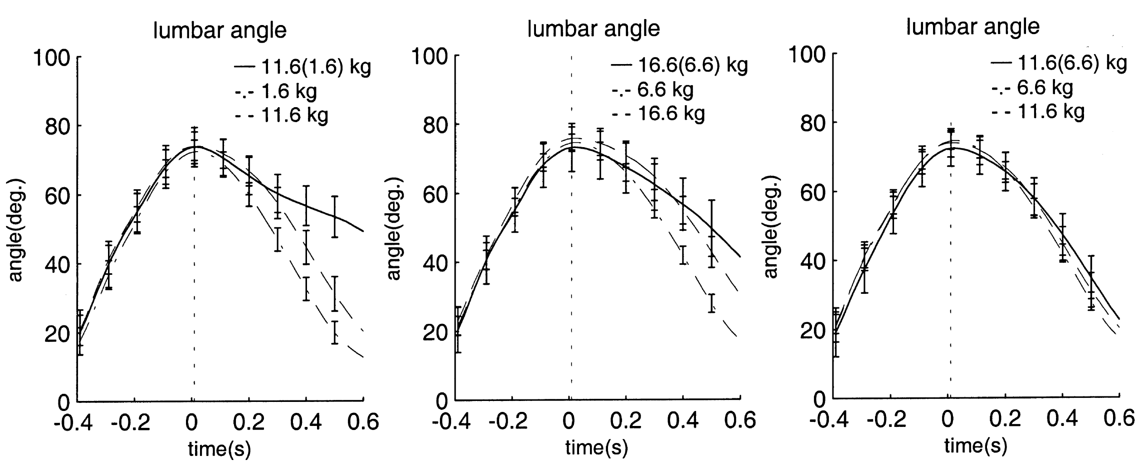

Fig. 2. Time series of the lumbar angle for the three mass change conditions. The solid line represents the unexpected mass change condition. The dotted line represents the heavy mass condition and the dashed–dotted line the light mass condition. The bars indicate one standard error of the mean. At time zero the box is grasped.

tivity which reached a peak after approximately 200 ms, was seen in all abdominal muscles (Fig. 3). During this peak, the maximum level of abdominal muscle activation was higher than the maximum activation observed in the 11.6 kg box condition with the correct mass knowledge. Back muscle activity was higher than the 1.6 kg box condition 200 ms after the subjects had grasped the unexpectedly heavy box (Fig. 3). The maximum level of activation of the lumbar back muscles was reached in this second burst of activation. This was not true for the thoracic muscles, for which the second peak in activity was less than the first peak.

The lifting of an unexpectedly 10 kg heavier box (11.6 kg) did not lead to loss of balance. None of the subjects had to make a step to regain balance. The risk of balance loss was increased, since the angular momentum was significantly less than in the correct mass knowledge conditions after the box grasp. Up to 400 ms after the box grasp the angular momentum was below or about zero (Fig. 4). The linear momentum was not significantly different from the 1.6 kg box condition, although it tended to be more positive immediately after the box grasp (Fig. 4).

3.2. *Influence of the expected load mass to be lifted*

Comparing the two 10 kg mass change conditions, it appeared that the maximum torque at the L5-S1 joint and the maximum low-back angle were not related to the expected load mass (Tables 2 and 3). In general, it can be said that the deviation from the planned movement was less marked when the subjects were expecting a 6.6 kg box than when the subjects were expecting a 1.6 kg box (Figs. 1 and 2).

The muscle activity during the lifting of an unexpectedly heavy box appeared to be related to the

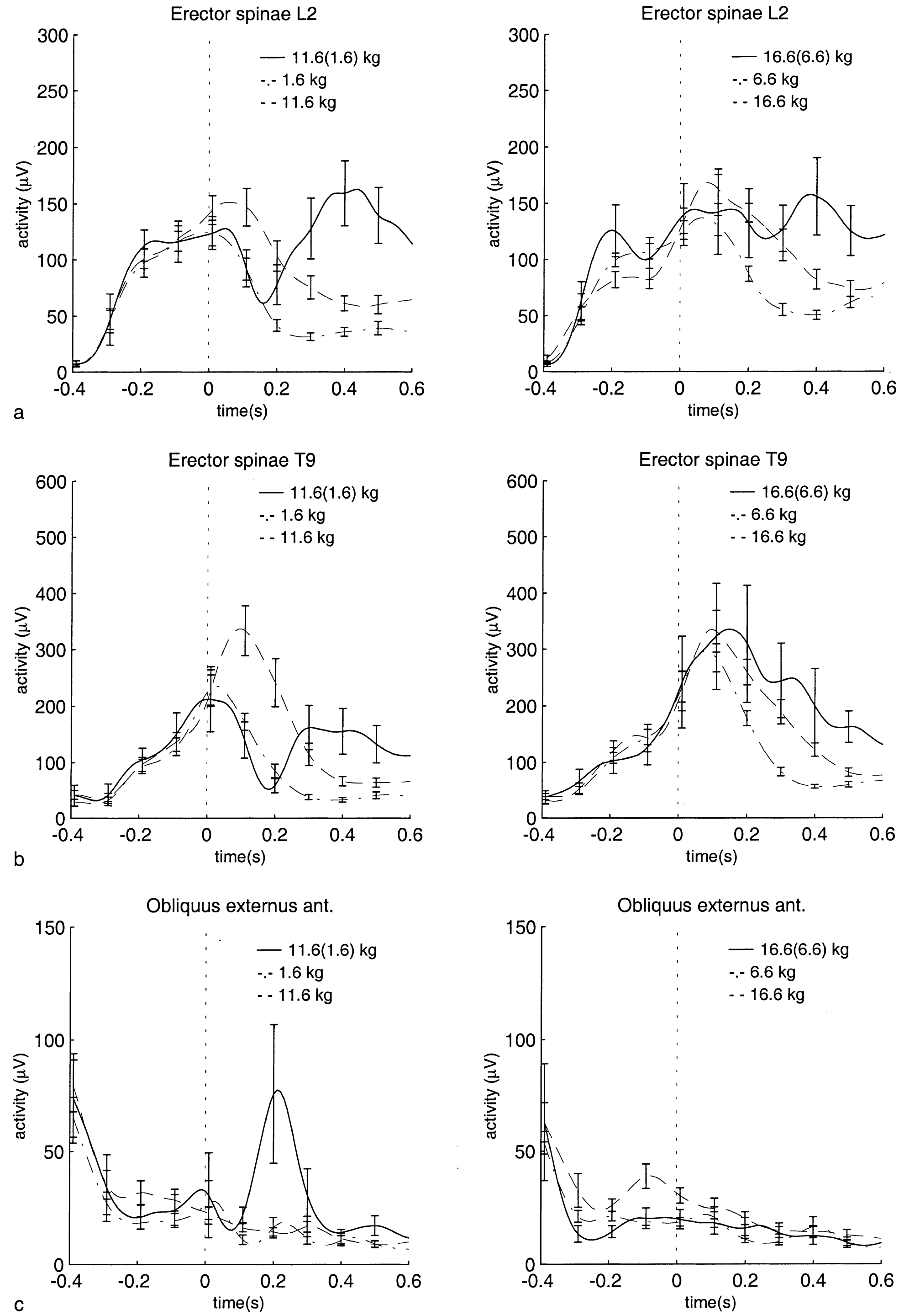

Fig. 3. Time series of the muscle activity for both 10 kg mass change conditions. (a) and (b) represent the m.erector spinae; (a) at the level of L2 and (b) at the level of T9. (c) represents the m. obliquus externus anterior. The solid line represents the unexpected mass change condition. The dotted line represents the heavy mass condition and the dashed-dotted line the light mass condition. The bars indicate one standard error of the mean. At time zero the box is grasped.

expected load mass. When the subjects expected to lift a 6.6 kg box, the abdominal muscles did not show as clear a burst of activity as in the condition in which the subjects expected to lift a 1.6 kg box. The back muscle activation did not show a second burst as clearly as in the condition in which the subjects expected to lift a 1.6 kg box either (Fig. 3).

The threat to balance appeared not to be consistently related to the expectation of the subjects about the mass. In the condition in which the subjects were expecting a

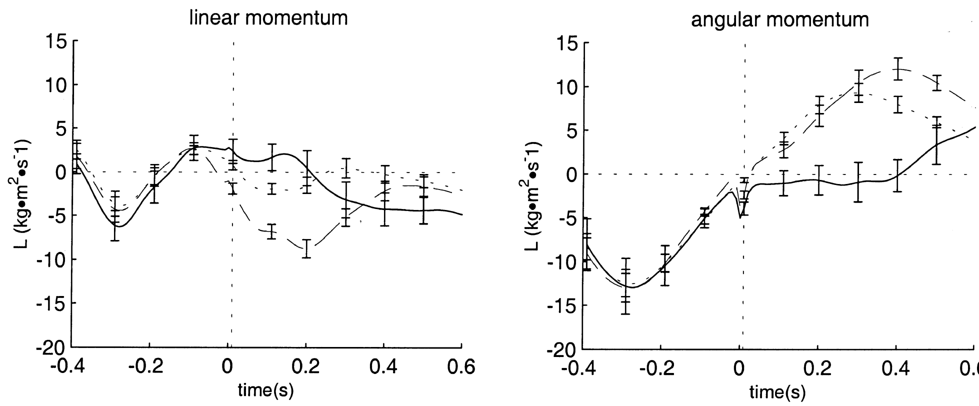

Fig. 4. Time series of the linear momentum (left) and the angular momentum (right) for the 11.6 (1.6) kg conditions. Linear momentum below zero implies a backward velocity; angular momentum below zero implies a forward rotation. The solid line represents the unexpected mass change condition. The dotted line represents the 11.6 kg box condition and the dashed–dotted line the 1.6 kg box condition. The bars indicate one standard error of the mean.

6.6 kg box, one subject had to make a step to regain balance. However, the difference in linear and angular momenta between the mass change condition and the light mass condition were less in the 6.6 kg condition than in the 1.6 kg condition (Fig. 4).

3.3. Influence of the size of perturbation on low-back loading

From a comparison of the 5 kg mass change condition and both 10 kg mass change conditions it appeared that the maximum torque at the L5-S1 joint and the maximum low-back angle were not related to the size of perturbation that had been imposed (Tables 1 and 2). The deviation from the planned movement in the 5 kg mass change condition was less than in both the 10 kg mass change conditions (Figs. 1 and 2). Until approximately 100 ms after the subjects lifted the unexpectedly heavier box, the muscle activation was similar to the light box condition. After this time, the muscle activation was not much different from the muscle activation in the heavy (11.6 kg) box condition.

The balance disturbance appeared to be related to the size of perturbation imposed. In the 5 kg mass change condition the momenta were not different from the momenta observed in the light box condition, in contrast with the 10 kg mass change condition.

4. Discussion

This study was designed to investigate the effects of lifting an unexpectedly heavy object on low-back loading and loss of balance in bimanual, whole body lifting tasks. To this end, the subjects had to lift a box, of which the mass was increased by 5 or 10 kg without them being informed. In all mass change conditions, the maximum torque at the lumbo-sacral joint and the maximum lumbar angle were the same as in the light mass condition. The abdominal muscles showed a burst of activity only in the condition in which the subjects were expecting to lift the 1.6 kg box, but were actually lifting the 11.6 kg box.

On basis of the results, it can be concluded that the subjects did not expect the mass of the box to be heavier. This cannot be concluded from the period before the subjects grasped the box, because no differences in movement execution were found between the different conditions (light, heavy and unexpected). Nevertheless, just after the box grasp it was seen that muscle activity in the mass change condition was similar to that found in the low load mass condition, but less than in the heavy mass conditions.

When the subjects were lifting an unexpectedly heavy box, the execution of the upward movement was slowed down (Fig. 2). This is probably the result of the low activation of the back muscles compared with the activation in the heavy box condition. The back muscle activation pattern appeared to be based on the expected low object mass and was adjusted to the actual box mass approximately 175 ms after the box grasp (Fig. 3). The slowing of the upward movement may limit the effect of the disturbance, since the amount of force that a muscle can develop at a given activation level increases when the contraction velocity decreases. Adaptations in torque at the L5-S1 joint were seen 250–300 ms after the subjects grasped the box (Fig. 1). The time elapse between the adaptation of back muscle activity and the torque at the L5-S1 joint can be accounted for by the electromechanical delay of these muscles [23].

In previous studies it was found that lifting a heavy object of an unknown mass did not increase the mechanical loading of the spine [13,24]. The same results were obtained in this experiment. Moreover, at all mass changes it was found that the maximum torque at the L5-S1 joint was smaller than the maximum torque which was found when the subjects were lifting the same load mass with the correct mass knowledge.

The lifting of an unexpectedly heavy box did not result in an increased maximum lumbar flexion. This indicates that the strain of the passive tissues (ligaments, tendons, lumbodorsal fascia and disc) did not increase. Therefore, it can be concluded that the risk of injury to the passive tissues does not increase when an unexpectedly heavy object is lifted. However, it cannot be excluded that the movements of individual vertebrae are more seriously disturbed than the movement of the trunk as a whole. Therefore no conclusive evidence with respect to injury risk can be presented.

The burst of abdominal muscle activity may increase the spinal compression and thereby the mechanical loading of the back. Abdominal muscle activity compresses the spine and generates a flexion torque which has to be compensated for by increased activity of the back muscles [25]. Due to the simultaneous activation of the flexor and extensor muscles, this increase in loading will not fully be seen in the net torque at the L5-S1 joint. However, the increased activation occurred later in the lifting movement, and thus in a more extended posture, with a torque that was half of the maximum torque (Fig. 1). It is not clear whether this burst of activity will cause a back load in excess of that during the maximal torque. The burst of abdominal muscle activation hinders the execution of the lifting movement, because it leads to a decreased extension torque. An increased level of abdominal activity was also found when an unexpected perturbation that caused flexion was imposed during standing [8,9] and following backward support perturbations in lifting [26]. Oddsson et al. [26] interpreted this burst of abdominal activity as part of the 'hip strategy' aimed at restoring balance. Our data support this interpretation in view of the increased balance threat in the condition in which the subjects were expecting to lift the 1.6 kg box, but were actually lifting the 11.6 kg box. An alternative explanation may be that the activation of the abdominal muscle is a 'flexion response' to stop the upwards movement. The fact that one subject actually dropped the box supports this explanation. Another possible explanation is that the abdominal muscle activation is increased to maintain stability of the trunk. The activation of the abdominal muscles may especially lead to an increased stability in the frontal plane, in other words it may prevent sideward buckling [27].

In contrast to the lifting of an unexpectedly light box [4], an unexpectedly heavy box did not lead to loss of balance. However, the angular and linear momenta indicate that a situation occurred with an increased chance of balance loss.

4.1. Influence of the expected mass to be lifted

The maximum torque at the low back was not different between the 10 kg mass change conditions. This was surprising, because it was suggested by Commissaris et al. [4] that expected load mass largely determines peak low-back loading. This unexpected result may be explained by the instruction to the subjects to lift as fast as possible. Lifting at a maximal speed may lead to maximal activation of the back muscles, because a maximal acceleration is required at the start of the lifting movement. Maximal activation of the back muscles will lead to a maximal extension torque independent of the object mass to be lifted. Conform to the above stated hypothesis of Commissaris et al. it was found that the maximum torques at the low back during the lifting of an unexpectedly heavy box were similar to the torques found when the subjects lifted the (light) mass they were expecting.

The activation of abdominal muscles appeared to be dependent on the expected object mass. It is seen that at the time of burst of abdominal muscle activity, the activity of the back muscles was lower in the condition in which the subjects were expecting to lift a 1.6 kg box than when the subjects were expecting to lift a 6.6 kg box. As a consequence, at this time the stability of the spine is lower in the unexpectedly 11.6 kg condition, because a low muscle activation leads to low stability of the spine [28,29]. The increased abdominal activation may serve as a stabilizer of the lumbar spine [27], which seems to be especially important when the initial muscle activation is low [9].

4.2. Influence of the size of the perturbation

The maximum torque at the L5-S1 joint was independent of the size of the perturbation. As a consequence, the lifting movement was slowed down more in the 10 kg mass change conditions than in the 5 kg mass change condition. The maximum lumbar angle was independent of the size of the perturbation. This is in contrast with the results of Krajcarski et al. [9], who found that increasing unexpectedly added mass resulted in larger forward rotations when subjects had to resist a forward flexion moment during stance. These differences may also be explained by the high muscle activation in all conditions caused by the instruction to the subject to lift a box as fast as possible.

5. Conclusion

Lifting an unexpectedly heavy mass as fast as possible could not clearly be shown to increase the loading of the low back, although a burst of abdominal muscle activity was found in one condition. The maximum torque of the low back was independent of the difference between the expected and actual lifted mass and the magnitude of the mass the subjects expected to lift. The threat to balance was increased when the mass was unexpectedly 10 kg heavier. These results do not fully support the assumed relation between lifting an unexpectedly heavy object and low-back injury. Further research is necessary to examine the effects of maximum lifting speed on the effects of lifting an unexpectedly heavier object.

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References

[1] Magora A. Investigation of the relation between low back pain and occupation. Part IV. Physical requirements: bending, rotation, reaching and sudden maximal effort. Scandinavian J Rehab Med 1973;5:186–90.
[2] Manning DP, Mitchell RG, Blanchfield LP. Body movements and events contributing to accidental and nonaccidental back injuries. Spine 1984;9:734–9.
[3] Frank JW, Brooker AS, DeMaio SE, Kerr MS, Maetzel A, Shannon HS, Sullivan TJ, Norman RW, Wells RP. Disability resulting from occupational low back pain. Part II: What do we know about secondary prevention? A review of the scientific evidence on prevention after disability begins. Spine 1996;21:2918–29.
[4] Commissaris DACM, Toussaint HM. Load knowledge affects low-back loading and control of balance in lifting tasks. Ergonomics 1997;40:559–75.
[5] Johansson RS, Westling G. Coordinated isometric muscle commands adequately and erroneously programmed for the weight during lifting tasks with precision grip. Exp Brain Res 1988;71:59–71.
[6] Fridén J, Sjöström M, Ekblom B. Myofibrillar damage following intense eccentric exercise in man. Int J Sports Med 1983;4:170–6.
[7] Adams MA, Hutton WC. Prolapsed intervertebral disc: a hyperflexion injury. Spine 1982;7:184–91.
[8] Thomas JS, Lavender SA, Corcos DM, Andersson GBJ. Trunk kinematics and trunk muscle activity during a rapidly applied load. J Electromyo Kinesio 1998;8:215–25.
[9] Krajcarski SR, Potvin JR, Chiang J. The in vivo dynamic response of the spine to perturbations causing rapid flexion: effects of pre-load and step input magnitude. Clin Biomech 1999;14:54–62.
[10] Lavender SA, Mirka GA, Schoenmarklin RW, Sommerich CM, Sudhakar LR, Marras WS. The effects of preview and task symmetry on trunk muscle response to sudden loading. Human Factors 1989;31:101–15.
[11] Manning DP, Shannon HS. Slipping accidents causing low-back pain in gearbox factory. Spine 1981;6:70–2.
[12] Pai Y-C, Rogers MW, Patton J, Cain D, Hanke TA. Static versus dynamic predictions of protective stepping following waist-pull perturbations in young and older adults. J Biomech 1998; 31:1111–8.
[13] de Looze MP, Boeken-Kruger MC, Steenhuizen S, Baten CTM, Kingma I, Dieen JH. van Trunk muscle activation and low back loading in lifting in the absence of load knowledge. Ergonomics, in press.
[14] Toussaint HM, Commissaris DA, Beek PJ. Anticipatory postural adjustments in the back and leg lift. Med Sci Sports Exer 1997;29:1216–24.
[15] Toussaint HM, Commissaris DACM, van Dieën JH, Reijnen JS, Praet SFE, Beek PJ. Controlling the ground reaction force during lifting. J Motor Behavior 1995;27:225–34.
[16] de Looze MP, Bussmann JBJ, Kingma I, Toussaint HM. Validation of a dynamic linked segment model to calculate joint moments in lifting. Clin Biomech 1992;7:161–9.
[17] McGill SM. A revised anatomical model of the abdominal musculature for torso flexion efforts. J Biomech 1996;29:973–7.
[18] van Dieën JH, Kingma I. Total trunk muscle force and spinal compression are lower in asymmetric moments as compared to pure extension moments. J Biomech 1999;32:681–7.
[19] Redfern MS, Hughes DB, Chaffin DB. High-pass filtering to remove electrocardiographic interference from torso recordings. Clin Biomech 1993;8:44–8.
[20] Potvin JR, Norman RW, McGill SM. Mechanically corrected EMG for the continuous estimation of erector spinae muscle loading during repetitive lifting. Euro J Appl Phys 1996;74: 119–32.
[21] Plagenhoef S, Evans FG, Abdelnour T. Anatomical data for analyzing human motion. Res Quart Exer Sport 1983;54:169–78.
[22] Kingma I, Toussaint HM, Commissaris DA, Hoozemans MJ, Ober MJ. Optimizing the determination of the body center of mass. J Biomech 1995;28:1137–42.
[23] van Dieën JH, Thissen C, van de Ven A, Toussaint HM. The electro-mechanical delay of the erector spinae muscle: influence of rate of force development, fatigue and electrode location. Euro J Appl Phys 1991;63:216–22.
[24] Butler D, Andersson GB, Trafimow J, Schipplein OD, Andriacchi TP. The influence of load knowledge on lifting technique. Ergonomics 1993;36:1489–93.
[25] Granata KP, Marras WS. An EMG-assisted model of trunk loading during free-dynamic lifting. J Biomech 1995;28:1309–17.
[26] Oddsson LIE, Persson T, Cresswell AG, Thorstensson A. Interaction between voluntary and postural motor commands during perturbed lifting. Spine 1999;24:545–52.
[27] Tesh KM, Dunn JS, Evans JH. The abdominal muscles and vertebral stability. Spine 1987;12:501–8.
[28] Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. Clin Biomech 1996;11:1–15.
[29] Crisco JJ, Panjabi MM. Postural biomechanical stability and gross muscular architecture in the spine. In: Winters JM, Woo SLYS, editors. multiple muscle systems: Biomechanics and movement organization. New York: Springer 1990:438–450.